METHODS OF TREATING OSTEOARTHRITIS WITH INDUCIBLE NITRIC OXIDE SYNTHASE INHIBITORS

5   **FIELD OF INVENTION**

This invention is generally related to nitric oxide synthase inhibitors and more specifically related to treating patients having osteoarthritis with nitric oxide synthase inhibitors.

BACKGROUND OF THE INVENTION

10   Nitric oxide (NO) is an inorganic reactive gas molecule, important in many physiological and pathological processes where it is synthesized by cells mediating vital biological functions.

Nitric oxide serves as a neurotransmitter in the brain, produced in small amounts on an intermittent basis in response to various endogenous molecular signals. Endothelial cells

15   lining the blood vessels also produce nitric oxide in small amounts, relaxing smooth muscle and regulating blood pressure. Indeed, the production of nitric oxide has a significant effect on the function of circulating blood cells such as platelets and neutrophils as well as on smooth muscle including blood vessels and other organs. Nitric oxide is also synthesized in the immune systems. Endotoxin and cytokines induce the production of large amounts of

20   nitric oxide in response to infectious and inflammatory stimuli, contributing to both host defense processes such as killing of bacteria and viruses as well as pathology associated with acute and chronic inflammation in a wide variety of diseases.

Nitric oxide is formed from L-arginine oxydation by at least three different isoforms of nitric oxide synthases (NOS) in mammalian cells divided into two distinct classes,

25   constitutive and inducible. The three NOS isoforms have been identified as:

(i) Endothelial Nitric Oxide Synthase (eNOS); (Type III NOS), a constitutive, Ca^{++}/calmodulin dependent enzyme, located in the endothelium releasing nitric oxide in response to receptor or physical stimulation;

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(ii) Neuronal Nitric Oxide Synthase (nNOS); (Type I NOS), a constitutive, Ca^{++}/calmodulin dependent enzyme, located in the brain releasing nitric oxide in response to receptor or physical stimulation; and

(iii) Inducible Nitric Oxide Sythase (iNOS); (Type II NOS), a Ca^{++} independent enzyme which is induced after activation of vascular smooth muscle, macrophages, endothelial cells, and a number of other cells by endotoxin and cytokines. Once expressed, this inducible NOS synthesizes large amounts of nitric oxide (NO) for long periods.

Nitric oxide generated by the constitutive enzymes acts as a transduction mechanism underlying several physiological responses. For example, eNOS is critical for production of nitric oxide, originally identified as endothelium derived relaxation factor (ERDF). The nitric oxide generated by eNOS regulates blood pressure in animals, blood flow in man, and prevents leucocyte adhesion.

On the other hand, the nitric oxide produced in large amounts by the inducible enzyme in is a cytotoxic effector molecule. As disclosed in U.S. Pat. No. 5,629,322, incorporated herein by reference, iNOS has been cloned from human liver and identified in more than a dozen other cells and tissues including smooth muscle cells, the kidney, and numerous epithelial cells in a variety of tissues including the lung and colon. This enzyme is induced upon exposure to lipopolysaccharide (LPS) and cytokines such as gamma interferon (IFN-γ), interleukin-1β (IL-1β), and tumor necrosis factor (TNF). Once induced, nitric oxide production by iNOS continues over a prolonged period of time, and the activity of iNOS is relatively independent of intracellular Calcium concentrations.

iNOS is implicated in conditions leading to cytokine-induced hypotension including septic shock, hemodialysis and IL-2 therapy in cancer patients. The excess production of nitric oxide generated by the inducible form of nitric oxide synthase also appears to contribute to cytokine-mediated inflammation, cytotoxicity and tissue damage. Accordingly, certain conditions have been identified where inhibiting nitric oxide production is advantageous. These conditions include arthritis, inflammatory bowel disease, cardivascular ischemia, diabetes, congestive heart failure, myocarditis, atherosclerosis, migraine, reflux

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esophagitis, diarrhea, irritable bowel syndrome, cystic fibrosis, emphysema, asthma, bronchiectasis, hyperalgesia (allodynia), cerebral ischemia (both focal ischemia, thrombotic stroke and global ischemia (secondary to cardiac arrest), multiple sclerosis and other central nervous system disorders, for example Parkinson's disease and Alzheimer's disease, and

5   other disorders mediated by NO including opiate tolerance in patients needing protracted opiate analgesics, and benzodiazepine tolerance in patients taking benzodiazepines, and other addictive behavior, for example, nicotine and eating disorders.

Further conditions in which there is an advantage in inhibiting NO production from L-arginine include systemic hypotension associated with septic and/or toxic shock induced by a

10   wide variety of agents; therapy with cytokines such as TNF, IL-1 and IL-2; as an adjuvant to short term immunosuppression in transplant therapy; and as a chemopreventative.

Although the potential uses for NOS inhibitors has been implicated in numerous diseases, the efficacy and outcome of using a NOS inhibitor to prevent, treat and cure many diseases has never been identified. For example, U.S. Pat. No. 5,629,322 at Col. 15

15   beginning line 60 lists an enormity of disease types where the NOS inhibitors may be used to treat a disease. However, the disease types are named as a result of speculation, without examples or analysis. Examples of other compounds which inhibit the production of nitric oxide can be found in U.S. Pat. Nos. 5,684,008 and WO 93/13055, each incorporated by reference as if written herein.

20   The effect and efficacy of NOS inhibitors and specifically selective iNOS inhibitors *in vivo* on disease progression for the many diseases has not been addressed. Therefore, the outcome and consequence of the use of the inhibitors on disease progression *in vivo* in many cases remains unknown. Although some information has been generated *in vivo* in inflammatory arthritis, which models human rheumatoid arthritis, suggesting that either non-

25   selective or in a few cases selective NOS inhibitors reduce disease severity, there are no reports of the use of NOS inhibitors to modulate experimental models of osteoarthritis. (18, 19, 21-24)

A need exists, therefore, to determine the effect NOS inhibitors have on the progression of osteoarthritis, and targeting new uses for NOS inhibitors and methods of treatment of osteoarthritis.

SUMMARY OF THE INVENTION

5 Accordingly, the present invention provides new methods of treating patients with osteoarthritis by modulating: 1) the amount of synovial fluid, 2) IL-1β levels; 3) the development of osteophytes; 4) the amount of cartilage degeneration; 5) metalloprotease production; and 6) acute joint injury through administering an effective amount of an iNOS inhibitor to the patient in need thereof. Specifically, the *in vivo* therapeutic efficacy of a

10 selective inhibitor of the inducible NOS, N-iminoethyl-L-lysine (L-NIL), was used to determine the effect on the progression of lesions in osteoarthritis, on joint metalloprotease production and activity, and the levels of IL-1β, prostaglandin E2 (PGE2) and nitrite/nitrate (the stable end products of nitric oxide) in synovial fluid.

Treatment with a selective inhibitor of iNOS reduced the severity of lesions,

15 demonstrating the effectiveness of the inhibitor of iNOS in attenuating the progression of the disease. In addition, the inhibitor, L-NIL, reduced the production and the activity of metalloproteases in cartilage, degradative enzymes known to play a major role in the pathophysiology of osteoarthritic lesions. The effect was shown to be mediated, in part by the suppressive effect of the inhibitor on IL-1β production.

20 In addition, iNOS inhibitors attenuate the enhanced production of PGE2 associated with an increased production of nitric oxide at sites of inflammation. Proinflammatory action of nitric oxide and PGE2 are both suppressed by the selective iNOS inhibitor. Treatment *in vivo* with a selective iNOS inhibitor resulted in a marked decrease in the level of nitric oxide and PGE2 in synovial fluid, and decreased the

25 expression of iNOS and cyclooxygenase-2 (COX-2), the enzyme repsonsible for the generation of PGE2.

This invention is the first to provide direct evidence that the *in vivo* suppression of nitric oxide production by selective inhibition of iNOS in osteoarthritic (OA) tissue

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is associated with a reduced *in situ* synthesis of interleukin-1 IL-1β by synovium, and metalloproteases by cartilage, as well as a reduced level of iNOS, peroxynitrite and COX-2, in OA tissue. This further elucidates the mechanisms responsible for the protective effect of the iNOS inhibitor on structural and biochemical changes seen in

5   experimental osteoarthritis.

OA lesions in cartilage develop as a result of an imbalance in the anabolic and catabolic processes that occur during the development of the disease. (1) The excess production of nitric oxide generated by the inducible form of nitric oxide synthase contributes to cytokine-mediated inflammation, cytotoxicity and tissue damage. The present invention

10 shows that the changes in the metabolism of chondrocytes in this disease are attributed, at least in part, to an increase in the synthesis of proinflammatory cytokines such as interluekin-1β (IFN-1β). This change in the function of the chondrocytes impacts the homeostasis of the cartilage matrix. (2)

Proinflammatory cytokines accelerate degradation of the cartilage matrix. (2,3) By

15 inducing the synthesis of proteolytic enzymes, cytokines interfere with the action of growth factors such as the insulin growth factor-1 (IGF-1) binding proteins. (4) Moreover, the inflammatory cytokines also reduce the synthesis of aggrecan, one of the major matrix macromolecules responsible for the functional properties of articular cartilage. (5,6) An increased production of nitric oxide (NO) is one of the main factors by which IL-β reduces

20 aggrecan synthesis. (5-7).

Nitric oxide is produced in large amounts by chondrocytes upon proinflammatory cytokine stimulation. (7-13) In contrast to normal cartilage, osteoarthritic cartilage spontaneously produces nitric oxide. (12-14) High levels of stable end product of nitric oxide have been found in the synovial fluid and serum of arthritic patients. (15) Similarly, the

25 messenger RNA and protein for inducible NO synthase, an enzyme responsible for the generation of cytotoxic levels of NO, have also been detected in synovial tissue from OA patients. (14-16).

Until the present invention, nitric oxide was only believed to contribute to the development of arthritic lesions. (17-19) This hypothesis was based on *in vitro* data showing that nitric oxide enhances metalloprotease (MMP) activity and inhibits proteoglycan synthesis. (8,20) Furthermore, it has been hypothesized that nitric oxide reduced the

5   synthesis of the IL-1 receptor antagonist in chondrocytes, a process possibly responsible for the enhanced effect of IL-1 on these cells. (13).

In the practice of the subject invention, seventeen dogs were used to test the effects of a NOS inhibitor *in vivo* on osteoarthritis. The OA dog model was created by sectioning the anterior cruciate ligament of the right stifle joint of twelve (12) dogs by a stab wound. Dogs

10   were divided into three (3) groups. Group I had five (5) dogs (n=5) made up of unoperated dogs that received no treatment and considered normal. Group II consists of six (6) dogs having osteoarthritis (OA dogs) without treatment. Group III consists of six (6) OA dogs that received oral L-NIL (10mg/kg) twice daily for ten (10) weeks beginning immediately after surgery.

15   The knees of the dogs treated with L-NIL showed a reduction in the incidence of osteophytes compared with the untreated dogs (58% vs. 92%) as well as in their size (1.92 ± 0.58 mm vs. 5.08 ± 0.66 mm). Macroscopically, L-NIL decreased the size of the cartilage lesions both on condyles and plateaus compared with the untreated dogs by about fifty percent (50%). At the histological level, the severity of cartilage lesions on the condyles and the

20   severity of synovial inflammation were both statistically decreased in the L-NIL treated versus the untreated dogs. Treatment with L-NIL also significantly decreased both general MMP and stromelysin activity in the cartilage and the levels of IL-1β, PGE$_2$ and nitrite/nitrate in synovial fluid.

It is the object of the present invention to provide new methods of treating

25   osteoarthritis by administrating a therapeutic effective amount of an iNOS inhibitor to a patient in need thereof.

Many other objects and purposes of the invention are clear from the following description of the invention.

While the specification concludes with claims particularly pointing out and specifically claiming the subject matter regarded as forming the present invention, it is believed that the invention will be better understood from the following detailed description of preferred embodiments.

5 **DETAILED DESCRIPTION OF THE INVENTION**

For the first time, a selective inhibitor of iNOS has been shown to reduce *in vivo* the progression of osteoarthritic lesions. *In vivo* treatment with a selective iNOS inhibitor also reduced the level of proinflammatory mediators, IL-1ß and PGE_2 and nitrite/nitrate levels in the synovial fluid, and showed a marked reduction in

10 metalloprotease activity and expression in cartilage and the volume of joint effusion. It also resulted in a decreased expression of iNOS, peroxynitrite and COX-2 in the cartilage.

In earlier models, osteophyte formation was shown to be one of the predominant structural changes of osteoarthritis, particularly on the femoral condyles. (25-28) The

15 formation and growth of osteophytes was hypothesized as being associated with inflamed synovium, mechanical factors, a variety of growth factors and cytokines. (33,34)

The subject invention teaches that treatment *in vivo* with a selective iNOS inhibitor reduces the growth of osteophytes and also decreases IL-1ß production.

20 Although in previous dog models, intraarticular injections of the IL-1 receptor antagonist was shown to decrease the formation of osteophytes, suggesting the role of IL-1ß in the genesis of osteophytes, the effect of an iNOS inhibitor on osteophyte formation was unknown. (33)

The dog OA model used to test the methods of the subject invention has been

25 previously used for testing the effects of anti-arthritic drugs *in vivo*. (25-28) This model is relevant to the human OA as it exhibits the development of progressive cartilage lesions. (32). In testing the method of the subject invention, cartilage lesions on both the condyles and plateaus of the untreated OA dogs at 10 weeks following

surgery were significant in size and grade, as expected in this model and in accordance with our previous reports (25-28). Treatment with the selective iNOS inhibitor markedly reduced the size of cartilage lesions by more than 50%. L-NIL had an effect on the lesion grade, more specifically on the condyles, which was also reflected by the

5 highly significant reduction in the histological severity of lesions. The protective effect of a selective NOS inhibitor was primarily attributable to the reduction in the severity of the structural changes (deepness of erosion) as indicated by the loss of safranin-*O* staining.

Our findings demonstrate selective iNOS inhibitors that mediate a reduction in

10 the cartilage matrix breakdown. This could be due to a direct action of the iNOS inhibitor, as reflected by the reduction of the nitrite/nitrate level in synovial fluid, but is also likely secondary to the inhibition of proteolytic enzyme activity. Recent reports suggest that NO may stimulate MMP synthesis and/or activity in chondrocyte *in vivo*. (8,20) Our findings provide evidence that the *in vivo* cartilage MMP activity can be

15 reduced by inhibiting iNOS activity and that the reduction in MMP activity in cartilage is associated with a decrease in the expression and synthesis of these proteases by chondrocytes. Therefore, the suppression of NO production by selective iNOS inhibitors preserved the cartilage proteoglycan content by reducing the level of MMP synthesis and activity in cartilage. Similarly, the decrease in severity of structural

20 changes simultaneously with the inhibition of collagenase activity explains how selective iNOS inhibitors provide protection for the collagen network underlying the cartilage structure. Other possible mechanisms by which iNOS inhibition may ultimately result in a decrease in the destruction of the cartilage include a reduction in chondrocyte apoptotic cell death and a reduction in the formation of the toxic highly

25 reactive oxidant, peroxynitrite.

The reduction in the degree of synovial inflammation in OA dogs treated with L-NIL compared to the synovium of untreated OA dogs is associated with a decrease in the level of IL-1ß in the synovial membrane and fluid. The decrease in IL-1ß synthesis

mediated by L-NIL occurs either directly or by an indirect mechanisms. Nonetheless, this reduction in IL-1ß contributes, at least in part, to the mechanism whereby the selective inhibitor reduces MPP synthesis *in vivo*.

In the treated dogs, the lower level of synovial inflammation was very striking,
5   both macroscopically and microscopically, and was observed mainly as a very significant reduction of the villous hyperplasia and the number of infiltrating mononuclear cells in the tissue. This finding explains how treatment with a selective inhibitor reduces the amount of synovial fluid effusion.

Similar anti-inflammatory effects of NOS inhibitors were previously reported in
10   carrageenan-stimulated air pouch and rat paw models of inflammation. The previous oral administration of L-NIL exerted other anti-inflammatory effects such as reducing the accumulation of nitrite/nitrate and the cellular infiltrate in the pouch fluid and the inflamed paw. In contrast, *in vivo* treatment of OA dogs with selective inhibitors reduced PGE_2 levels or PG isomerase activity as well as its expression. (37, 38)

15   **Experimental Groups**

Seventeen adult crossbred dogs (2-3 years), weighing 20 to 25 kg each, were used in this study. Surgical sectioning of the ACL of the right knee, through a stab wound, was performed on 12 dogs as previously described (25-28). Prior to surgery, animals were anesthetized intravenously with pentobarbital sodium (25 mg/kg) and
20   incubated. Following surgery, the dogs were kept in animal care facilities for one week, then sent to a housing farm, where they were free to exercise in a large pen.

The dogs were randomly separated into three treatment groups: Group I (n = 5) was made up of unoperated dogs that received no treatment (normal); Group II (n = 6) were OA dogs that received no treatment; Group III (n = 6) were OA dogs that were
25   given 10 mg/kg L-NIL twice a day.

Drug Administration and Circulating Drug Level

L-NIL was administered twice daily at a dose of 10 mg/kg at 8 and 16 hours. The drug was given orally as a liquid solution. Drug treatment was initiated

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immediately after surgery for a duration of 10 weeks, after which time the animals were sacrificed. The concentration of L-NIL was measured in the serum mid-treatment and at the end of the study following 10 weeks of treatment, and in the synovial fluid at the end of the study only. L-NIL was measured using electrospray MS/MS (Sciex API

5   III) in the multiple selection monitoring mode using the fragment ion (m/z 84) that originates from the compound.

Macroscopic Grading of Lesions

Immediately after sacrifice, the right knees of the dogs were dissected, placed on ice, and the synovial fluid aspirated and the volume measured. Each knee was

10   examined for gross morphological changes, including the presence of osteophyte formation and cartilage lesions, as previously described (25-28). Examinations were performed by two independent, blinded observers. The degree of osteophyte formation was graded by measuring the maximal width (mm) of the spur on each femoral condyle. The cartilage changes on the medial and lateral femoral condyles and tibial

15   plateaus were graded separately under a dissecting microscope (Stereozoom, Bausch & Lomb, Rochester, NY).

The depth of erosion was graded on a scale of 0 to 4 as follows: 0 = surface appears normal, 1 = minimal fibrillation or a slight yellowish discoloration of the surface, 2 = erosion extending into superficial or middle layers, 3 = erosion extending

20   into deep layers, 4 = erosion extending to subchondral bone. The surface area of the articular surface changes was measured and expressed in mm^2.

Histological Grading

Histological evaluation was performed on sagittal sections of cartilage from the lesioned areas of each femoral condyle and tibial plateau as described (25-28).

25   Specimens were dissected, fixed in 10% buffered formalin and embedded in paraffin for histological evaluation. Serial sections (5 μm) were stained with safranin-O. The severity of the OA lesions was graded on a scale of 0 to 14, by two independent observers, using the histological/histochemical scale of Mankin *et al* (29). This scale

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evaluates the severity of OA lesions based on the loss of staining with safranin-O (scale 0-4), cellular changes (scale 0-3), invasion of the tidemark by blood vessels (scale 0-1) and structural changes (scale 0-6). On this last scale, 0 indicates normal cartilage structure and 6 signifies erosion of the cartilage down to the subchondral bone. This scoring system was based on the most severe histological changes within each cartilage section.

Representative specimens of synovial membrane from the medial and lateral knee compartments were also dissected from underlying tissues. The specimens were fixed in 10% buffered formalin, embedded in paraffin, sectioned (5 μm) and stained with hematoxylin-eosin. Two synovial membrane specimens were examined for each compartment, with the highest score from each compartment retained. The average was calculated and considered as a unit for the whole knee. The severity of synovitis was graded on a scale of 0 to 10 (14) by two independent observers, adding the scores for 3 histologic criteria: synovial lining cell hyperplasia (scale 0-2), villous hyperplasia (scale 0-3), and degree of cellular infiltration by mononuclear and polymorphonuclear cells (scale 0-5).

Metalloprotease (MMP) Activity Assay

After macroscopic examination was performed and sections were taken for histological evaluation, the remaining cartilage from the femoral condyles, tibial plateaus and synovial membranes was carefully dissected.

Extraction of MMP was carried out as described (28). Briefly, the tissue was sliced and homogenized in the extraction buffer (50 mM Tris HC1, 10 mM $CaCl_2$, 2 M guanidine HCl, 0.05% Brij-35, pH 7.5). The mixture was stirred overnight at 4°C, and then centrifuged (18,000g, 30 minutes, 4°C). The supernatant was extensively dialyzed (48 hours at 4°C) against an assay buffer (50 mM Tris HCl, 10 mM $CaCl_2$, 0.2M NaCl, 0.05% Brij-35, pH 7.5) using Spectrapor 4 dialysis tubing with a 12,000 Da cut-off (Spectrum Medical Industries, Los Angeles, CA).

The collagenase activity in tissue extract was measured using telopeptide-free type I collagen from rat tail tendon acetylated with $|^{14}C|$-acetic anhydride (30). One hundred microliters of $|^{14}C|$-collagen suspension (12,000 DPM) was incubated under the following conditions: 1) with an 100 μl aliquot of tissue extract, in the presence of 1mM aminophenylmercuric acid (APMA), and 2) with an 100 μl aliquot of tissue extract, containing 1 mM APMA and 25 mM ethylenediaminetetraacetic acid (EDTA) serving as a blank. Each solution was incubated for 48 hours at 30°C, after which time each was centrifuged at 12,000g for 15 minutes at 4°C. The radioactivity contained in the supernatant was determined using a beta scintillation counter (Beta Rack, Model 1218; LKB, Stockholm, Sweden). The total enzymatic activity was expressed in units per gram of tissue wet weight (w.w.), with one unit corresponding to the hydrolysis of 1 μg of substrate/hour at 30°C. Over 90% of the collagenase activity was inhibited by EDTA.

The general MMP activity in the cartilage extract was measured by the method of Chavira *et al* (31) using azocoll (Calbiochem-Novabiochem International, San Diego, CA) as the substrate. One hundred microliters of the azocoll suspension was incubated in a manner similar to the collagenase assay, but with 1 mM 1,10-phenanthroline serving as the blank. After incubation (48 hours at 37°C), this solution was centrifuged (12,000g for 15 minutes at 4°C), and the supernatant's optical density determined by spectrophotometric analysis. The general MMP activity was expressed in units per gram of tissue w.w., in which one unit corresponded to the hydrolysis of 1 μg of substrate/hour at 37°C. The azocoll digesting activity in the extracts was inhibited by more than 90% by 1,10-phenanthroline.

Enzyme Immunoassay

The level of IL-1ß in the synovial fluid was determined using a specific solid phase, double antibody ELISA. PGE_2 was measured by an enzyme immunoassay. The IL-1ß kit was from BioSource International (Camarillo, CA), and the PGE_2 kit from Cayman Chemical Co. (Ann Arbor, MI). Sensitivity of the assay was 0.3 pa/ml for

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IL-1ß and 29 pg/ml for PGE$_2$. The measurements were performed in duplicate, and according to the manufacturer's specifications. The reaction was measured on a micro-ELISA Vmax photometer (Molecular Devices Corp., Menlo Park, CA, USA). They were expressed as total pg or ng in the synovial fluid of the joint.

5   **Nitric Oxide Assay**

Nitrite and nitrate in synovial fluid were determined using a fluorometric assay as described (21). Briefly, synovial fluid was filtered through a 10,000 Da cut-off Ultrafree microcentrifuge filter unit (Millipore, Bedford, MA) at 14,000 rpm for 15 minutes. To convert nitrate to nitrite, 5-10 µl filtered synovial fluid was incubated in

10   20 mM Tris, pH 7.6 containing 40 µM NADPH and 14 mU of nitrate reductase in a final volume of 100 µl. After incubation for 5 minutes at 20°C, the fluorometric reaction was initiated by the addition of 10 µl of 0.05 mg/ml 2,3-diaminonaphthalene dissolved in 0.62M HCl. After 10 minutes at 20°C, the reaction was terminated with 10 µl 1.4 N NaOH. Fluorescence was measured at the wavelengths 365/450 nm

15   (excitation/emission) using a fluorescence plate reader (IDEXX Laboratories, Westbrook, ME). Nitrite was expressed as total nmol in the synovial fluid of the joint.

Immunohistochemical Studies

Cartilage specimens from condyles and plateaus, a well as synovial membrane, were processed immunohistochmical analysis as previously described. Briefly,

20   specimens were fixed in 4 % paraformaldehyde for 24 hours, then embedded in paraffin. Section (7 µm) of paraffin-embedded specimens were placed on Superfrost Plus slides (Fisher Scientific, Nepean, Ontario, Canada), deparaffinized in toluene, hydrated in a graded series of ethanol, and preincubated with chondroitinase ABC (0.25 units/ml) in phosphate buffered saline (PBS; Sigma Aldrich Canada Ltd., Oakville,

25   Ontario, Canada) for 60 minutes at 37°C. Following this, the specimens were washed in PBS, then again in 0.3% hydrogen peroxide/methanol for 30 minutes. Slides were further incubated with 2% normal serum (Dimensions Laboratories, Mississauga, Ontario, Canada) for 20 minutes, blotted and then overlaid with: i) a rabbit polyclonal

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antibody (IgG) against iNOS (100 μg/ml, dilution 1/100, Santa Cruz Biotechnology Inc., Santa Cruz, CA, USA) for 2 hours at room temperature in a humidified chamber; ii) a rabbit polyclonal (IgG) anti-nitrotyrosine antibody (dilution 1/100, Dr. P. Manning, Searle/Monsanto R&D, St. Louis, MO, USA) for 1 hour at room temperature;

5   iii) with a mouse monoclonal antibody (IgG) against rhIL-1ß (1 mg/ml, dilution 1/25, BioSource International, Montreal, Quebec, Canada0; iv) a rabbit polyclonal antibody (IgG) against rhstromelysin-1 (MMP-3; 500 μg/ml, dilution 1/1000, Oncogene Science, Cambridge, MA, USA); v) a mouse monoclonal antibody against rhcollagenase (MMP-1; 100 μg/ml, dilution 1/500, Oncogene Science); or vi) a rabbit polyclonal antibody

10   (IgG) against rhCOX-2 (dilution 1/500, Oxford Biomedical Research Inc., Oxford, MI, USA). With the exception of the antibody against MMP-3, which was incubated for 18 hours at 4°C, all antibodies were incubated for 1 hour at room temperature.

Each slide was washed three times in PBS (pH 7.4) and stained using the avidin-biotin complex method (Vectastain ABCkit; Dimension Laboratories). This method

15   entails incubation in the presence of the biotin-conjugated secondary antibody for 30 minutes at room temperature, followed by the addition of the avidin-biotin-peroxidase complex for 45 minutes. All incubations were carried out in a humified chamber, and the color developed with a 3,3'-diaminobenzidine (Dimension Laboratories) containing hydroxide peroxide.

20   To determine the specificity of staining, three control procedures were employed according to the same experimental protocol: 1) use of absorbed immune serum (1 hour, 37°C) with a 10 to 20-fold molar excess of recombinant or purified antigen; 2) omission of the primary antibody; and 3) substitution of the primary antibody with an autologous preimmune serum. The purified antigens used in this study were rhIL-1ß

25   (Genzyme, Cambridge, MA, USA), rhMMP-1, rhMMP-3, rhiNOS and rhCOX-2 (Monsanto/Searle, St. Louis, MO, USA), and nitrotyrosine (Sigma-Aldrich, St. Louis, MO, USA).

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Several sections were made from each block of cartilage, and three slides from each specimen were processed for immunohistochemical analysis. Each section was examined under a light microscope (Leitz Orthoplan; Wild Leitz, Ville St-0Laurent, Quebec, Canada), and photographed with Kodak Edtachrom 64 ASA film (Rochester,
5   NY, USA).

Morphometric Analaysis

Cartilage

Cartilage samples from all medial and lateral femoral condyles and tibial plateaus were processed. From each cartilage specimen, three slides were processed
10   for immunohistochemical studies. Quantification of the different antigens in cartilage and synovium was done using our previously published method with slight modifications. The level of protein synthesis was estimated by determining the number of chondrocytes staining positive within the different layers of cartilage. Each cartilage section was divided into six microscopic fields (X 40; Leitz Diaplan), three
15   fields at each of the following two zones: the superficial and upper intermediate layers, and the lower intermediate and deeper layers. The superficial layer includes chondrocytes of the immediate surface characterized by discoidal cells following the split-line pattern of the dominant fibrillar orientation, and the upper 50% of the transitional zone characterized by round or spheroidal cells. The deep layer includes
20   cells of the lower 50% of the transitional zone and those aligned in columns. For each arthritic specimen, it was ensured prior to evaluation that an intact cartilage surface could be detected, and used as a marker for validation of morphometric analysis.

The total number of chondrocytes, and the number of chondrocytes staining positive for the specific antigen, were estimated for full-thickness cartilage. The final
25   results were expressed as the percentage of chondrocytes staining positive for the antigen (cell score), with the maximum score being 100%. Each slide was subjected to double-blind evaluation, resulting in a variation of < 5% between the scores. The data

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obtained from the medial lateral condyles and tibial plateaus were considered as independent for the purposes of statistical analysis.

Synovial Membrane

5   For synovial membrane analysis, a cell score of the different specimens was determined for each section using our previously published method. Each specimen was divided into 10 different areas: five microscopic fields (X 40) at the synovial lining cell level, and five in the sublining area of the synovial membrane. The percentage of cells staining positive fore the specific antigen was evaluated in each field as described above for cartilage. The percentage of cells with positive staining 10   was averaged for all five fields in each area of the synovium (synovial lining cells and mononuclear cell infiltrate). Each slide was evaluated blindly by two independent observers, resulting in a variation of < 5% between the two scores. Cell count scores were given separately for the synovial lining cells and mononuclear cell infiltrate, with the maximum for each area being 100%.

15   **Statistical Analysis**

        Mean values and standard errors of the mean were calculated. Statistical analysis was done using the Mann-Whitney U-test. P values less than 0.05 were considered significant.

20   <u>**RESULTS**</u>

Circulating Drug Levels

        The concentration of L-NIL was measured in the serum at mid-treatment and in the serum and synovial fluid following 10 weeks of treatment. Samples were obtained 2h following drug administration. The mean concentration ± SEM of L-NIL in the 25   serum at mid-treatment and at the end of treatment was 201 ± 33 and 119 ± 24 μM, respectively. The concentration of L-NIL in the synovial fluid at the end of treatment was 96 ± 18 μM, demonstrating access of the compound to the joint.

Macroscopic Findings

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Osteophytes: In OA dogs, osteophytes were present in 92% of the condyles. Their mean ± SEM width was 5.08 ± 0.66. In dogs treated with L-NIL, osteophytes were present in only 58% of the condyles, and their size was smaller (1.92 ± 0.58 mm; $P < 0.002$) compared to the untreated OA dogs. Condyles from unoperated (normal)

5 dogs were of normal appearance, and no osteophytes could be seen.

Cartilage: The cartilage on condyles and plateaus of normal dogs were macroscopically normal in appearance. In untreated OA dogs, cartilage lesions of moderate grade and size were present on both condyles and plateaus, with slightly more severe lesions on plateaus. Dogs treated with L-NIL presented a marked reduction in

10 the severity of lesions on the condyles, with a decrease of approximately 50% in size and 20% in grade.

Synovial Membrane: Synovia from normal dogs had a white luster and were transparent in appearance. Synovia from OA dogs were hypertrophic and demonstrated a reddish-yellow discoloration and contained a large number of blood vessels. In OA

15 dogs treated with L-NIL, the synovia were thinner and contained fewer blood vessels and the discoloration was less intense compared to untreated OA dogs.

Microscopic Findings

Cartilage: Cartilage from unoperated dogs had a normal histological appearance with the exception of a few dogs who showed either a minimal loss of

20 safranin-*O* staining at the superficial layer or minimal irregularities of the cartilage surface. Specimens from untreated OA dogs had morphological changes including cartilage fibrillation and fissures, hypercellularity and cloning, and a loss of safranin-*O* staining. The histological score for the lesions on the condyles was similar to that on the plateaus. In the L-NIL-treated OA dogs, the lesions on the condyles were

25 significantly less severe ($P < 0.005$) compared to the untreated OA dogs. This difference was largely due to a decrease in severity of structural changes and loss of safranin-*O* staining. In accordance with macroscopic observation, no difference

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between the two OA groups (untreated and L-NIL-treated) was observed in the severity of histologic lesions on the plateaus.

Synovial Membrane: The histology of the synovia from the unoperated dogs was within normal limits, with the exception of a few specimens that had a minimal

5 and focal villous hyperplasia (score = 0.50 ± 0.34). Synovia from the untreated OA dogs were thick, had numerous villosities, and showed synovial lining cell hyperplasia and moderate infiltration of mononuclear cells. The synovial inflammation in the OA dogs treated with L-NIL was less severe than the untreated OA dogs (score = 2.50 ± 0.18 vs 4.42 ± 0.47; $P < 0.004$). The reduction in the inflammation score following

10 treatment with L-NIL resulted primarily from a reduction in the intensity of villous hyperplasia and mononuclear cell infiltration.

Metalloprotease Activity

General MMP Activity: The mean general MMP activity in cartilage and synovium was significantly higher ($P < 0.004$ and $P < 0.02$, respectively) in untreated

15 OA dogs as compared to normal dogs. In the L-NIL-treated OA dogs, the enzyme activity was reduced in both cartilage and synovial membrane and a statistical difference reached for cartilage ($P < 0.004$).

Collagenase: The mean activity of collagenase found in cartilage and synovium from OA dogs was significantly higher ($P < 0.002$) compared to the activity found in

20 normal dogs. The enzyme activity in both tissues was reduced by treatment with L-NIL, and again a statistical difference reached only for cartilage ($P < 0.004$).

Values of IL-Iβ, Nitrite/Nitrate, and PGE₂ in Synovial Fluid

The volume of synovial fluid increased from 0.3 ± 0.04 ml in normal dog joints to 6.8 ± 1.0 ml in the joints of untreated OA dogs. Treatment with L-NIL reduced the

25 volume by 68% to 2.4 ± 0.8 ml ($P < 0.009$). The total amount of IL-1ß in the synovial fluid of the normal dogs was very low (0.1 pg). A significantly higher level of IL-1ß (32.9 ± 15.3 pg, $P < 0.001$) was found in the untreated OA dogs. In OA dogs treated with L-NIL, the level of IL-1ß was significantly decreased to near normal amounts (0.5

± 0.2 pg) having a $P < 0.004$ value when compared to the untreated OA. The total amount of nitrite/nitrate was also markedly increased in untreated OA synovial fluid (96.4 ± 17.9 nmol, $P < 0.001$), as compared to that in normal (6.5 ± 0.8 nmol). The L-NIL-treated OA dogs exhibited a 53% decrease (48.6 ± 12.9 nmol, $P < 0.04$) in the

5   total nitrite/nitrate content of synovial fluid over that of untreated OA dogs. Moreover, the total amount of PGE_2 was also reduced from 9.4 ± 5.4 ng in untreated OA dog synovial fluid to 0.8 ± 0.3 ng in L-NIL-treated OA dogs ($P < 0.009$). Due to sample limitations, the amount of PGE_2 was not measured in normal dogs.

Synovial Membranes

10   a)   IL-1 ß

In unoperated dogs, IL-1 ß was detected in only a very few cells in the synovial lining. In the untreated OA dogs, staining for IL-1 ß was found in all specimens, and in both the synovial lining cells and the mononuclear cell infiltrate. The cell scores of OA synovial membrane specimens were significantly higher than those of unoperated dogs, both for

15   mononuclear cell infiltrate and synovial lining cells.

In the L-NIL-treated dogs, although IL-1 ß was expressed in all specimens, the cell score was significantly lower than in the untreated OA dogs, both for synovial lining cells ($P < 0.008$) and mononuclear cell infiltrate ($P < 0.008$). Controls using absorbed immune serum showed only background staining.

20   b)   iNOS and 3-nitrotyrosine

With the exception of an occasional synovial lining cell, the synovial membrane of unoperated dogs showed no specific staining. In the OA synovial membrane of untreated dogs, a strong staining for both iNOS and 3-nitrotyrosine was observed in a small percentage of the lining and mononuclear infiltrating cells. The cell score for both lining and

25   mononuclear cells was significantly higher when compared to unoperated dogs. There was a significant decrease in cell score for both lining and mononuclear cells, with the exception of the cell score for iNOS in mononuclear cells, in L-NIL-treated dogs. Controls using absorbed immune serum showed only background staining.

19

c)   COX-2

In unoperated dogs, COX-2 staining was detected in only a few cells in the synovial lining. In the untreated dogs, there was a large number of cells, both in the synovial lining and the mononuclear cell infiltrate, that showed a positive staining for COX-2. Osteoarthritic

5   dogs treated with L-NIL presented a marked decrease in the number of cells staining positive for COX-2, both in the lining and the mononuclear cell infiltrate.

Cartilage

a)   Metalloproteases

Only a few cells stained positive for collagenase-1 in the superficial and deep layers of

10   condyles and plateaus in cartilage from unoperated dogs. The cell score was substantially higher in OA cartilage from operated untreated dogs, with a greater proportion of positive cells in the superficial layers. In contrast, operated dogs treated with L-NIL showed a marked and significant decrease in the collagenase-1 cell score in both condyles and plateaus.

Results for stromelysin-1 (General MMP) were similar to those for collagenase-1,

15   with a marked and significant increase in cell score in OA cartilage from operated untreated dogs, with similar changes in both condyles and plateaus. Treatment with L-NIL significantly reduced stromelysin-1 cell score in both condyles and plateaus.

b)   iNOS and 3-nitrotyrosine

Only in few cells in cartilage specimens from condyles and plateaus of unoperated

20   dogs showed specific sytoplasmic staining for iNOS. These cells were located in both the superificial and the deep layers. There was a large and significant increase in number of chondrocytes expressing iNOS in OA cartilage, in both condyles and plateaus, that was significantly higher than specimens from unoperated dogs. The cell scores were similar in the superficial and deep layers. There was a very significantly decrease in the iNOS cell score in

25   condyles and plateaus in the operated dogs treated with L-NIL.

The pattern for 3-nitrotyrosine staining was almost identical to that of iNOS. Only a few cells stained positive in all layers of cartilage from condyles and plateaus of unoperated dogs, while a marked and significant increase in cell score was found in OA cartilage. The

20

number of positive chondrocytes was evenly distributed between the superficial and deep

layers. Cartilage specimens from dogs treated with L-NIL showed a significantly lower cell

score compared to that of untreated dogs, in both condyles and plateaus.

c)   COX-2

5   The level of COX-2 was greatly increased in OA cartilage, whereas the number of

chondrocytes staining positive for this enzyme was five-to-eight times greater than normal

cartilage. OA dogs treated with L-NIL presented a very significant reduction in cell score on

condyles and plateaus.

10

TABLE I. EXPRESSION OF IL-1ß IN DOG SYNOVIAL TISSUE

Groups	Synovial Lining (cell score) (p)®	Mononuclear Cells (cell score) (p)
Unoperated* (n = 5)	5.20 ± 0.65 ($p < 0.008$)	0.23 ± 0.23 ($p < 0.008$)
OA§ (n = 5)	58.71 ± 3.20	46.36 ± 4.76
L-NIL@ (n = 5)	33.32 ± 2.52 ($p < 0.008$)	18.51 ± 2.84 ($p < 0.008$)

Values are the mean ± SEM.
15 * Sacrificed animals neither operated nor treated.
§ Operated animals sacrificed and tissue examined at 12 weeks after surgery.
@ Operated animals sacrificed and tissue examined at 12 weeks after surgery; L-NIL given orally (10 mg/kg/qd/po) for 12 weeks beginning immediately after surgery.
20 ® Statistical analyses done by Mann-Whitney U-test; p values compared to OA group.

TABLE II. EXPRESSION OF iNOS AND 3-NITROTYROSINE IN DOG SYNOVIAL TISSUE

	iNOS		3-Nitrotyrosine	
Groups	Synovial Lining (cell score)®	Mononuclear Cells (cell score)	Synovial Lining (cell score)®	Mononuclear Cells (cell score)
Unoperated * (n = 5)	0.002 ± 0.002 (p < 0.008)	0.002 ± 0.002 (p < 0.06)	1.36 ± 0.2 (p < 0.008)	0.002 ± 0.002 (p < 0.008)
OA§ (n = 5)	8.34 ± 0.96	5.26 ± 2.07	14.84 ± 3.57	8.87 ± 1.86
L-NIL@ (n = 5)	1.09 ± 0.39 (p < 0.008)	2.46 ± 2.15 NS	2.05 ± 0.3 (p < 0.008)	2.36 ± 0.84 (p < 0.02)

5   Values are the mean ± SEM.
*   Sacrificed animals neither operated nor treated.
§   Operated animals sacrificed and tissue examined at 12 weeks after surgery.
@   Operated animals sacrificed and tissue examined at 12 weeks after surgery; L-NIL given orally (10 mg/kg/qd/po) for 12 weeks beginning immediately
10 after surgery.
®   Statistical analyses done by Mann-Whitney U-test; p values compared to OA group.

15

TABLE III. MACROSCOPIC GRADING OF FEMORAL CONDYLES AND TIBIAL PLATEAUS

GROUP	No. of Animals	FEMORAL CONDYLES Size (mm^2)	Grade (0-4 scale)	TIBIAL PLATEAUS Size (mm^2)	Grade (0-4 scale)
Unoperated*	5	0	0	0	0
OA†	6	15.33 ± 3.52	1.42 ± 0.19	17.02 ± 3.49	1.42 ± 0.29
L-NIL§	6	7.33 ± 2.32	1.08 ± 0.26	9.75 ± 2.45	1.33 ± 0.26

Values are the mean ± SEM.
*   Sacrificed animals were neither operated nor treated.
†   Animals were sacrificed and tissue was examined 10 weeks after surgery.
20 §   Animals were sacrificed and tissue was examined at 10 weeks after surgery. L-NIL (10 mg/kg twice daily) was given orally for 10 weeks, beginning after surgery.

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TABLE IV. EXPRESSION OF COLLAGENASE (MMP-1) AND STROMELYSIN (MMP-3) IN DOG CARTILAGE

Groups	Collagenase- (MMP-1)		Stromelysin-1 (MMP-3)	
	Femoral Condyle (cell score)®	Tibial Plateau (cell score)	Femoral Condyle (cell score)®	Tibial Plateau (cell score)
Unoperated* (n = 5)	4.12 ± 0.42 (p < 0.0001)	5.43 ± 0.71 (p < 0.0001)	4.62 ± 0.61 (p < 0.0001)	5.98 ± 0.52 (p < 0.0001)
OA§ (n = 5)	30.28 ± 3.94	36.25 ± 3.58	43.48 ± 1.98	44.94 ± 2.17
L-NIL@ (n = 5)	10.02 ± 2.26 (p < 0.0002)	18.25 ± 1.97 (p < 0.0003)	34.45 ± 2.14 (p < 0.006)	33.21 ± 1.90 (p < 0.0001)

5   Values are the mean ± SEM.
*   Sacrificed animals neither operated nor treated.
§   Operated animals sacrificed and tissue examined at 12 weeks after surgery.
@   Operated animals sacrificed and tissue examined at 12 weeks after surgery; L-NIL given orally (10 mg/kg/qd/po) for 12 weeks beginning immediately
10   after surgery.
®   Statistical analyses done by Mann-Whitney U-test; p values compared to OA group.

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TABLE V. EXPRESSION OF INDUCIBLE NITRIC OXIDE SYNTHASE (iNOS) AND 3-NITROTYROSINE IN DOG CARTILAGE

Groups	Inducible Nitric Oxide Synthase (iNOS)		3-Nitrotyrosine	
	Femoral Condyle (cell score)®	Tibial Plateau (cell score)	Femoral Condyle (cell score)®	Tibial Plateau (cell score)
Unoperated* (n = 5)	5.49 ± 0.30 (p < 0.0001)	6.98 ± 0.42 (p < 0.0001)	5.36 ± 0.49 (p < 0.0001)	6.27 ± 0.36 (p < 0.0001)
OA§ (n = 5)	47.11 ± 1.98	45.82 ± 2.13	36.68 ± 2.75	45.50 ± 2.35
L-NIL@ (n = 5)	26.46 ± 2.04 (p < 0.0001)	35.82 ± 1.97 (p < 0.001)	21.81 ± 2.14 (p < 0.0004)	27.30 ± 1.88 (p < 0.0001)

5   Values are the mean ± SEM.
*   Sacrificed animals neither operated nor treated.
§   Operated animals sacrificed and tissue examined at 12 weeks after surgery.
@   Operated animals sacrificed and tissue examined at 12 weeks after surgery; L-NIL given orally (10 mg/kg/qd/po) for 12 weeks beginning immediately
10   after surgery.
®   Statistical analyses done by Mann-Whitney U-test; p values compared to OA group.

TABLE VI. COX-2 EXPRESSION IN DOG CARTILAGE

Groups	Femoral Condyles (% of positive cells) (p)®	Tibial Plateaus (% of positive cells) (p)
Unoperated* (n = 5)	5.02 ± 0.36 ($p < 0.0001$)	7.64 ± 0.52 ($p < 0.0001$)
OA§ (n = 5)	40.99 ± 3.26	39.74 ± 2.70
L-NIL@ (n = 5)	18.20 ± 2.29 ($p < 0.0001$)	27.68 ± 2.12 ($p < 0.001$)

5   Values are the mean ± SEM.
*   Sacrificed animals neither operated nor treated.
§   Operated animals sacrificed and tissue examined at 12 weeks after surgery.
@   Operated animals sacrificed and tissue examined at 12 weeks after surgery; L-NIL given orally (10 mg/kg/qd/po) for 12 weeks beginning immediately
10   after surgery.
®   Statistical analyses done by Mann-Whitney U-test; p values compared to OA group.

15   The following references, patents and applications are hereby incorporated within this

application as if written herein:

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DESCRIPTION OF FIGURES

Figure 1

35   Levels of general metalloprotease activity in articular cartilage and synovial

membrane of dogs. Values are units/gms of tissue wet weight (w.w.). P values are versus the

10 week OA group, by Mann-Whitney U test.

Figure 2

Levels of collagenase activity in the cartilage and synovial membrane of dogs. Values

40   are units/gms of tissue wet weight (w.w.). P values are versus the 10 week OA group, by

Mann-Whitney U test.

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